BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

In the Matter of	)	
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	)	MM Docket No. 00-39
	)	
Review of the Commission's	)	
Rules and Policies Affecting the	)	
Conversion to Digital Television	)	
	)	

To: The Commission

Comments of the Advanced Television Technology Center

These comments to the Commission's DTV biennial review report on two projects undertaken by the Advanced Television Technology Center (ATTC) which bear directly on the future performance of both DTV transmission and reception. Specifically, we report on the 1998-1999 design and demonstration of a Digital On-Channel Repeater, which carries the DTV signal to remote or hard-to-reach areas, and an ongoing RF signal data capture project, which will assist manufacturers in improving the performance of their DTV receivers. These projects that address the critical questions of coverage and reception are therefore important to the DTV implementation process.

I. Digital On-Channel Repeater.

In 1998, the ATTC began to investigate the feasibility of using a Digital On-Channel Repeater (DOCR) within the ATSC 8-VSB digital television system to extend the signal to areas the main antenna cannot reach. Such a repeater would have minimal impact on the allocation table or result in additional interference to digital or analog stations. ATTC performed an analysis which concluded that a properly engineered DOCR should work in conditions where the target audience was shielded from the main transmitter by terrain. This is a common condition that has lead to the widespread use of translators throughout the United States.

Details of the project and results of the field tests are attached. In brief, ATTC selected a site in Charles Town, West Virginia that is terrain-shielded from the Washington, D.C. area by a range of low-level mountains. It leased a tower known as the Neersville Tower atop the Blue Ridge mountain range. On September 4, 1998, ATTC conducted an error free demonstration (which was witnessed by a member of the Commission's Office of Engineering and Technology) of the DOCR system at Charles Town Racetrack. Subsequent field tests showed that the DOCR is a reliable means to provide DTV service to areas that would otherwise be unserved. Additional projects are ongoing in Oregon and Utah where Oregon Public Broadcasting and DTV Utah are using the DOCR technology developed and proven by ATTC. Utah has over 600 active NTSC translators that are used to supply television service to over half of the population of the state.

On-channel repeater capability is an important adjunct to any DTV system regardless of transmission modulation, and ATTC has shown that a DOCR can work reliably with the ATSC 8-VSB system under the conditions that have been tested.

II. RF Signal Capture.

In 1999, ATTC began a project to capture RF signals in a digital format for playback and analysis by DTV equipment manufacturers attempting to improve their receivers. There was, and continues to be, a need to improve the performance of DTV receivers. Much of the early testing had been done in the laboratory, which has limited capability in simulating the interference environment within which a DTV receiver must work. Only when experimental DTV stations began to go on air did DTV equipment manufacturers have an opportunity to witness how their sets performed in a real-world environment.

Unfortunately, the interference environment to which a DTV receiver is subjected is constantly changing. It is impossible for equipment manufacturers using off air signals to fully quantify the channel characteristics. It is difficult and expensive to perform field tests for each change equipment manufacturers make to their receivers. In late 1999, the ATTC built and tested a RF signal capture system based on a Celerity high-speed, high-resolution data acquisition recorder. The initial area for data capture is Washington, D.C. because it is rich in availability of DTV signals with 6 channels on air, and has challenging reception conditions. The goal of the RF signal capture project is to obtain a broad sample of reception conditions that represent the real-world signal environment for equipment manufacturers.

It is expected that the Washington, D.C. data captures will be completed by the end of June 2000. The goal is to capture data files at 30 different sites for each of the 6 channels with both an indoor antenna and outdoor antenna. Thus, there are 12 data files captured at each site. Other locations will be used in the future to expand the database and provide a broader range of interference conditions. These data files will be made available to the entire broadcast industry.

* * * *

The DOCR and RF data capture projects will assist broadcasters and equipment manufacturers in perfecting the transmission and reception of DTV signals. ATTC believes that the future of DTV is very bright, and we are making scientific and technical contributions to ensure that the U.S. DTV system is as robust as it can be.

Respectfully submitted,

/s/ Paul K. DeGonia
Paul K. DeGonia
Executive Director
Advanced Television Technology Center, Inc.
1330 Braddock Place
Suite 200
Alexandria, Virginia 22314
Tel: 703-739-3850
Fax: 703-739-3230

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Jonathan D. Blake /s/ JDB
Jonathan D. Blake
Ellen P. Goodman
Covington & Burling
1201 Pennsylvania Ave. NW
Washington D.C. 20044
Tel: 202-662-6000
Fax: 202-662-6291

Its Attorneys

DIGITAL ON CHANNEL REPEATERS FOR DIGITAL TELEVISION

ABSTRACT

The Advanced Television Technology Center (ATTC) successfully developed and demonstrated an On Channel Repeater for Digital Television (DTV). The demonstration repeated WETA-HD's primary DTV signal beyond the Blue Ridge Mountains into Charles Town, West Virginia. The system used the same channel for retransmission as the primary transmitter.

A large number of frequency translator channels in the United States have been reallocated to DTV primary channels. The DOCR provides local broadcasters with a means to replicate or extend their current analog coverage while having no impact on the DTV allocation table. The DOCR allows rebroadcast of a DTV signal, without frequency shifting, into an area previously unable to receive the originally transmitted signal. The DOCR can replace the traditional frequency translator as the tool to overcome terrain obstructions and to extend coverage into areas with weak coverage or significant multipath interference. This paper describes the subsequent field test of the ATTC DTV On Channel Repeater.

INTRODUCTION

The DOCR is a mechanism where a DTV signal is received, processed, then retransmitted on the original transmit frequency. The DOCR is more efficient spectrally when compared with frequency translators because channel shifting is not employed. The traditional analog frequency translator requires two or more channels to accomplish the same coverage. This efficiency will be vital during the DTV transition period when each current station in the USA will be transmitting on an analog and digital channel simultaneously.

An additional advantage of a DOCR over a frequency translator is the simplicity of System Information (SI) table rebroadcast. The translator would need the channel and frequency fields to be modified to reflect the retransmit channel change. This would require modifying the bitstream at the frequency translator site, precluding a simple analog solution. The DTV signal would need to be demodulated and then remodulated after the appropriate fields have been updated.

OVERVIEW

The DOCR is practical due to the adoption of digital transmission techniques in television broadcasting. These techniques allow strong multipath conditions to exist in noisy environments yet still deliver error free data to receivers. Repeaters for analog service have been extremely difficult to implement due to multipath created by co-locating receive and retransmit antennas. The high isolation required for repeating an analog signal has lead to the use of alternate channels for rebroadcast. This difficulty necessitated the adoption of frequency translators for analog television service.

ATTC has identified two techniques for rebroadcast of a DTV signal whether it is on-channel or on a frequency shifted channel. The first technique is the non-regenerative method, or otherwise known as the analog method. The signal is received, filtered, then retransmitted. This method is the least expensive to construct, requires the least control, and allows higher retransmit power. There are no provisions for any manipulation of the bitstream including correcting any errors that may have occurred in the primary transmission path.

The second method is the regenerative method, also known as the digital method. This method demodulates the signal to the ATSC transport stream then remodulates the bitstream back to the original channel. This method requires broadcast quality demodulators and modulators, precision frequency sources, and other expensive devices. In exchange, the digital method allows error correction at the repeater in addition to the ability to edit the bitstream including MPEG-2 bitstream splicing and remultiplexing.

The analog method has significantly better receive characteristics at the receiver. This is due to the retransmitted signal being an identical copy of the primary signal. This results in a ghost being created at the repeater and retransmitted by the repeater. At the receiver, the residual primary signal and the repeated signal also form a ghost as a result of the two different paths the primary and the repeated signals may take. These ghosts are easily repaired by a digital modem. Figure 1 shows the tap energy from an adaptive equalizer highlighting the various delay times at the receiver as a result of a DOCR.

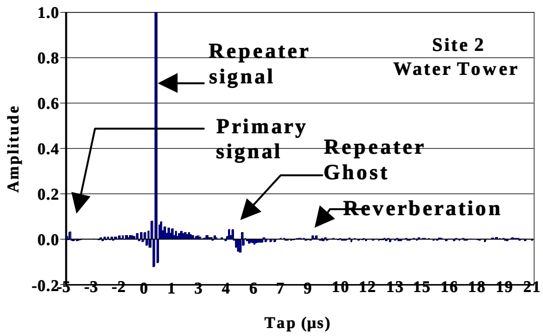

Figure 1. Receiver Dynamic Equalizer tap weights relative to the main signal

The digital method results in a non-coherent signal due to the field/frame alignment variance between the primary and the repeated signals. In addition, information related to the state of the interleaver is not preserved through the repeater. This causes the dominant impairment at the repeater and at the receiver to be co-channel DTV into DTV (D→D) interference. Digital modems are much more sensitive to co-channel interference than to multipath interference. The difference in performance between the non-regenerative (D→E) and the regenerative (D→D) system performance is in excess of 10 dB.

As a result, the non-regenerative system is preferred over regenerative systems for a single repeat action. The non-regenerative method degrades the spectrum with each repeat action, adding multipath with each hop. If a multi-hop design is required, a regenerative system can be employed to re-create a clean spectrum near the final DOCR.

A related issue concerning the non-regenerative repeater is the possibility of a pre-ghost with time differences greater than 4 μsec. The pre-ghost can occur when the residual primary signal exceeds the co-channel interference threshold but is less than the multipath interference threshold. Under these conditions, the pre-ghost is at least as long as the delay inherent in the main channel filter in the repeater. This is usually a SAW filter with corresponding delays of 3-4 μsec. The differing paths to the receiver from the primary transmitter and through the repeater add to the total delay time. Fortunately, for path lengths of greatest time differences, the angle formed between the repeater and the primary transmitter allows the use of receive antenna directivity to increase signal selectivity.

Nevertheless, a receiver should have the capability of handling a pre-ghost of at least 5 μsec to operate in a DOCR environment. Many 8-VSB receivers already meet this criterion. Nearly all receivers have a total FIR filter length of approximately 24 μsec, but with a variety of window locations i.e. the start and stop times differ amongst manufacturers. Next generation FIR filters will allow equalizers with a depth of nearly 48 μsec for a receiver.

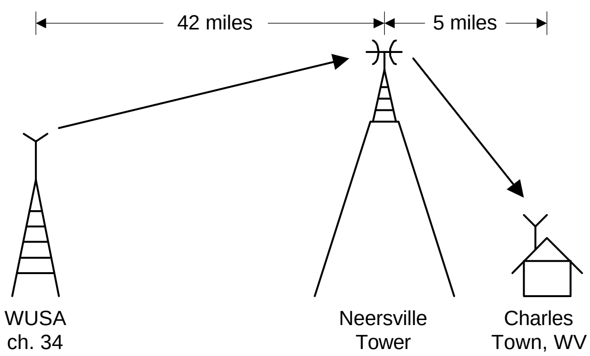

Figure 2. System Topology of the DOCR

Field Test Parameters

Figure 2 illustrates the system topology. The repeater design consists of a primary transmitter located in Washington, a repeater in Neersville, WV, and a target receive area in Charles Town, WV.[1] The distance between the primary transmitter and the repeater was approximately 42 miles. The distance from the repeater to the receive area is 5-10 miles from the repeater. The total distance from the primary transmitter to the repeater is in excess of 50 miles. The repeater was located atop a 1000 foot HAAT ridge isolating Charles Town, WV from Washington DC.

The primary transmitter was provided by WUSA, a Gannet owned CBS affiliate. WUSA transmits their DTV signal on US channel 34 (590-596 MHz) at an ERP of 636 kW with an omnidirectional antenna. The demonstration was performed with WETA-HD, which was operating with an experimental license on WUSA's final allotment. The field tests were conducted using the final owner (WUSA) on channel 34 once the Washington stations moved to their final channels.

Between the primary transmitter and the repeater's receive antenna was a direct line-of-sight path, providing a stable error free signal for retransmission. The repeater's retransmit ERP was 1.2 kW using a 60° beamwidth transmit antenna. The antenna pattern was ideal for concentrating the repeater's signal into the populated areas surrounding Charles Town. The bulk of the tests were conducted using the non-regenerative repeater design.

The test truck conformed to the design used in virtually all ATSC field tests. The truck was built and operated by CBS engineers for ATTC. The procedures used for each measurement followed procedures developed and approved by the Advisory Committee on Advanced Television Service (ACATS).

FIELD TEST RESULTS

51 sites were selected for testing. Figure 3 shows the distribution of sites around the repeater. The field tests were divided into four categories. These tests were known as the grid, cluster, arc, and radial tests.

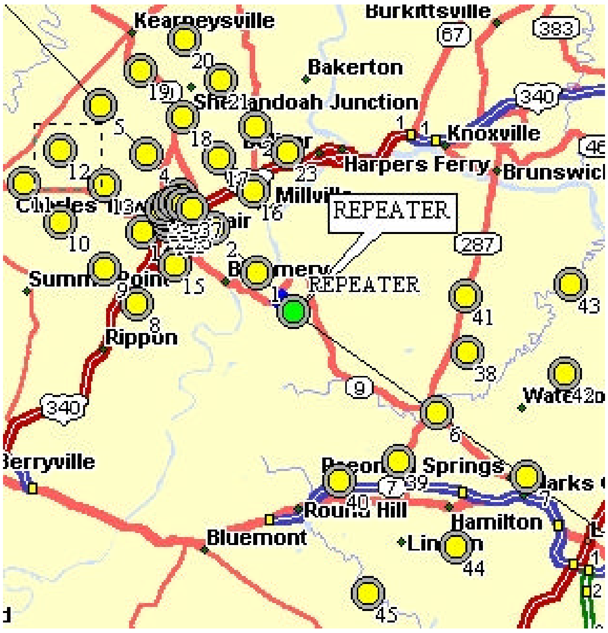

Figure 3. DOCR field test sites

At each site, the field strength of WUSA's primary transmitter was measured and recorded. The repeater's field strength was then measured and recorded while WUSA was still transmitting. Each site was then

A map showing the grid sites is shown in Figure 4. The grid is located Northwest of the repeater. Twenty sites were selected and arranged in a 4x5 matrix. The first row was 4 miles from the repeater and the farthest row was 10 miles from the repeater.

The objective of the grid tests was to determine whether the repeater improved reception in areas where the signal was weak. The area the grid covered was relatively large and with a variety of localized terrain types including small hills, dells, and assorted farm buildings.

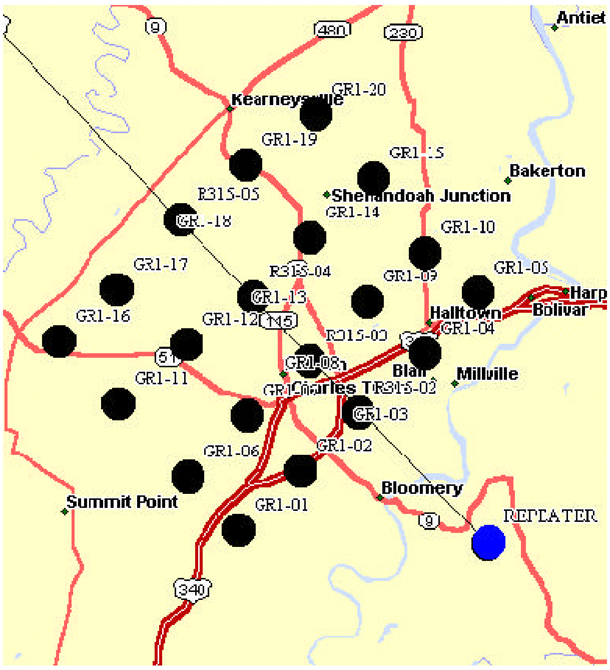

Figure 4. Grid test sites

examined for absolute and relative field strengths.

Table 1 shows the average results from the grid test. In general, the signal strength improved by nearly 20 dB with the repeater. In addition, the site margin improved by 16 dB. Site margin is defined as the excess signal strength above 41 dBµV/m, the value determined by the FCC to be the minimum acceptable receive signal strength for a DTV receiver.[2] Sites below the minimum signal strength had a site margin of 0 dB.

15 sites out of 20 received the primary signal without the repeater for a success rate of 75%. When the repeater was turned on, the number of successful sites increased to 19 out of 20 total sites. The final success rate was 95% with the repeater operational. The failed site was determined to be caused by a receiver that was unable to correct a 4 µsec leading ghost.

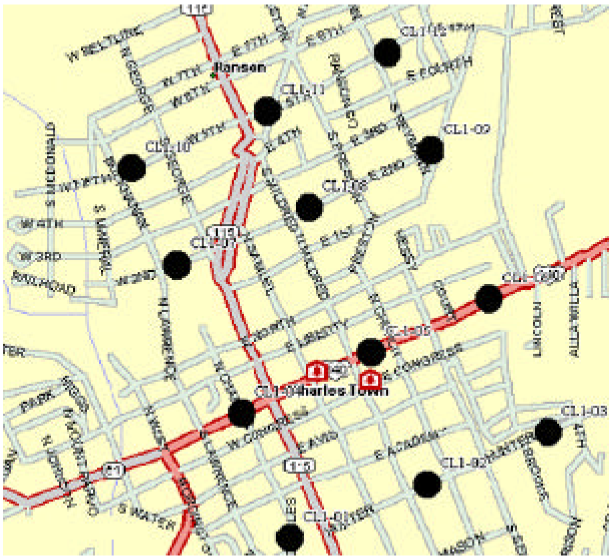

Figure 5. Map of the cluster test locations

Figure 5 shows the cluster map. The cluster is located in downtown Charles Town, WV. The cluster is approximately in the center of the grid. The objective of the cluster sites was to measure the performance of the repeater in an urban area.

Transmitter	Field Strength	Site Margin
WUSA	52.9 dBµV/m	9.6 dB
Repeater	72.5 dBµV/m	25.2 dB
Difference	19.5 dB	15.6 dB

Table 1. Average results of the grid tests

Twelve sites were selected in the center of the town. The same method was used for each site as the grid test. The cluster contained one important difference, the inclusion of the effects of closely spaced buildings.

Table 2 lists the average results of WUSA, the repeater, and a comparison of the two. WUSA's primary signal suffered much higher attenuation in addition to much more severe multipath. Several sites had adequate field strength, but failed due to high multipath. The repeater significantly increased signal strength at every site. The increase in received signal strength was so great, the effects of multipath were nullified with the repeater on.

Only 7 sites out of 20 received the primary signal without the repeater for a success rate of 58%. When the repeater was turned on, all sites in the cluster were successful.

The next series of tests was the arc tests. Two arcs were formed behind the repeater i.e. on the primary signal side of the repeater. The arcs were 6 miles and 10 miles respectively and are shown in Figure 6. The primary objective of the arc test was to ensure the repeater did not radiate appreciable energy into an area that was already capable of DTV reception.

Transmitter	Field Strength	Site Margin
WUSA	45.8 dBµV/m	4.1 dB
Repeater	73.6 dBµV/m	27.8 dB
Difference	27.8 dB	23.8 dB

Table 2 Average results of the cluster tests

At each site in the arc, a measurement of WUSA was performed with the antenna pointed at WUSA. The repeater was then turned on and the signal from the repeater was measured with the antenna pointed at the repeater. The signal strength at all sites for WUSA was acceptable with receive margins in excess of 10 dB. The repeater's field strength was not measurable indicating excellent front-to-back isolation of the re-transmit antenna.

The final series of tests was the radial tests. A radial was drawn from the repeater along the boresight of the retransmit antenna. The sites are shown in Figure 7. Since the primary transmit antenna and the repeater's antenna are within 15 degrees of each other, this configuration represents the worst case for simultaneous reception of both DTV signals.

The primary objective of the radial test was to compare the regenerative repeater design with the non-regenerative repeater design. The method for testing each site was to measure WUSA's field strength, then slowly bring up the repeater's ERP until reception failure occurred. This point was recorded. The repeater ERP was then brought up again until service was restored and this point was recorded. The difference between each failure point and WUSA is the Desired-to-Echo (D→E) ratio. The first point is a lagging ghost case and the second point is the leading ghost case. The test was then repeated for the regenerative design.

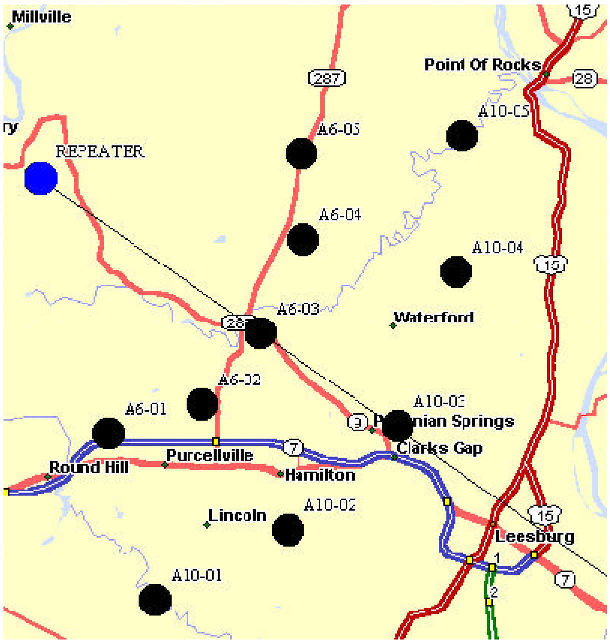

Figure 6. Map of the arc test locations

For the non-regenerative case, the D→E ratio was measured to be less than 5dB for lagging ghosts but in excess of 15 dB for leading ghosts. The reference receiver was unable to correct for the leading ghost, resulting in measurements appearing as co-channel D→D interference. A consumer set top box on the truck was able to correct the ghost, yielding results on the order of 7-8 dB D→E.

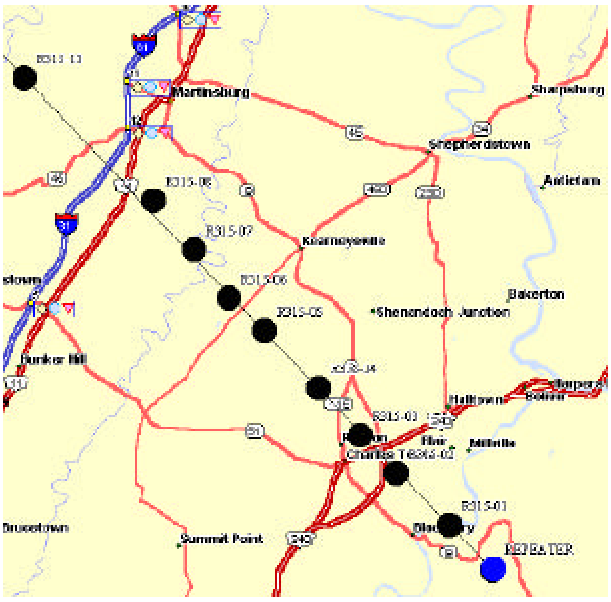

Figure 7. Map of the radial test locations

The regenerative tests confirmed the D→D ratio to be 16 dB for both leading and lagging ghosts. The repeater's retransmit power also needed to be reduced to minimize the effects of co-channel interference at the repeater. The radial tests were relative measurements, which allowed ATTC to continue the test.

CONCLUSIONS

ATTC has determined the DOCR can be used in a terrain isolated topology to extend reliable coverage into areas of marginal DTV service. The DOCR also is able to improve coverage in areas where low signal strength and strong multipath exists by increasing the received signal strength well above the original primary-only signal. Consumer receivers can receive a repeated DTV signal successfully and in some cases better than a reference receiver.

Non-regenerative, i.e. analog repeaters provide better performance at the receiver due to the ability of the equalizer to repair signal damage caused by ghosting. Repeater retransmit power in the non-regenerative case is higher because of the high tolerance to ghosts in the final receiver. Regenerative repeaters can correct errors, modify the transmitted bitstream, and reconstitute the

DTV spectrum at the cost of lower tolerance to co-channel interference and higher implementation cost. One possible application of a regenerative repeater is to improve multi-hop repeater chains. An additional potential use of a regenerative DOCR is to localize a signal for either demographic or geographic purposes.